Low Complexity Non Maximally Coefficient Symmetry Multi Rate Filter Bank for Wideband Channelization

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Abstract: For extracting the individual channels from input signal of wideband, Software Radio Channelizer was often used on multi-standard wireless communication. Despite the effective channelizer design that decreases the complexity of computational, delay and power consumption is challenging. Thus, to promote the effectiveness of the channelizer, we have provided the Non-Maximally Coefficient Symmetry Multirate Filter Bank. For this, a sharp wideband channelizer is designed to be using the latest class of masking responses with Non-maximally Decimated Polyphase Filter. Moreover, coefficient symmetry is incorporated into the Non-Maximally Coefficient Symmetry Multirate Filter Bank to improve the hardware efficiency and functionality of the proposed schemes. To prove the complexity enhancement of the proposed system, the design is analyzed with communication standard with existing methods.

Keywords- Circuits for Communications, Filters, Internet of Things (IoT), wireless communication, delay and power consumption, Filter Bank, Polyphase Filter

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1. Introduction

Communication developments, includes the IoT, cooperative communication, cognitive radio, has rapidly arisen, representing a large range of application environments and signal processing requirements. In wideband systems, high sampling frequencies and data rates describe the signal processing operations, due to the higher number of operations each second [1]. The complexity of the hardware and the energy usage of broadband systems [2] is gradually improved by these higher processing demands. Smart green technology consisting of high throughput and less power consumption describes the new outlook in rapidly growing communication technology [3].

In SDR-based multi-standard radios, the channelizer normally identifies specific radio channels from the wideband input signal [4]. Software radio channelizes generally include digital down-conversion, channel filtering as well as sampling rate conversion. In cognitive radio system, based radio software was an essential component. Modern SDR receivers can accept many channels with various communication standards is of importance on provided bandwidth. In the radio channel application, the Multirate digital filter bank was used to eliminate number of narrowband channels from the wideband input signal [5, 6].

Extracting multiple narrowband channels from received wideband signal, digital filter banks in SDR receiver [7] usually employ a channelizer. Because filter bank channelization was mounted instantly after ADC, which should perform at increased sampling rate in digital front-end of receiver. If the most calculationally intensive components of a wideband receiver system are the channelizer, this block absorbs power and to make it computer-intensive in low. Therefore, the efficient architectures of low complexity are necessary for the channelizer to be incorporated.

A filter bank scheme is one of the successful solutions to fulfill these criteria. The hardware and computational complexity of the channelizer based on filter banks is, preferring efficient wideband channelization. These days, the spectrum has become restricted, and sharp filters are necessary within wideband channelizer to achieve proper spectrum usage. Sharp filters frequently help in minimizing interaction with the adjacent channel [8]. In terms of monitoring and budget, understanding sharp transition width responses on filter bank-depend system was very costly.

In the study papers, several methods of designing the filter bank are usable. Uniform filter banks and here channels were of identical bandwidths [9], non-uniform filter banks where channels are unequal bandwidths [10], also reconfigurable filter banks where channels are variable bandwidths FRM is the commonly utilized method for generating channels of low complexity and sharp transition distance.

2. Related Work

In [11] developed the compact, system-level modeling method in design of a digital channelizer. The approach applies effective MDP methods on innovative ways to design optimization for reconfigurable channelization processing. Technique was used to produce the runtime reconfiguration for time-varying environment. But, high computational complexity, delay, wrong tuning is possible utilizing this approach. To promote the low complexity and reconfigurability of filter banks in SDR receivers, the Fourier transform (DFT) depend FB and the implementations fulfill stringent criteria of Software Defined Radio receivers was provided in [12]. Filter bank depends upon FRM will utilized as a effective replacement for a per-channel method to be less complex, and the FB depend on coefficient decimation method is being utilized as the substitute to FB with less complexity. A MFIR filter was being used as the prototype filter in provided structure to achieve a sharp transition width with less hardware complexity. A proposed structure used in an SDR channel for the understanding of multiple channels was, compared to state of the art structures, reconfiguration as well as hardware efficient. Discrete Fourier altered filter for the design of non-uniform near-perfect reconstruction to implement reconfigurable software-defined wireless radio channeling systems include very minimum hardware complexity. By combining adjacent channels of the uniform modified Discrete Fourier transform, a non-uniform modified Discrete Fourier transform filter bank was acquired. In this channelized design, the complexity, area, power are critical problems. For this, uniform channelization coefficient decimation based filter bank utilizing the FIR filter is introduced [13] for SDR channelization. By coefficient decimation, the low pass, high pass, bandpass responses were provided. The maximum resampling ratios require low-pass digital filters include a very narrow transition band leads to increased calculational complexity and makes filter design difficult. Thus Frequency Response Masking process, that breaks filter with the narrow transition band to yet another set of filters with decreased design requirements in [14]. It reduces the quantity of non-zero coefficients and an effect, the computational complexity of resampler is diminished by using the FRM filter. The maximum decimated filter bank should not varied from multiple channels, that is not flexible for the low-complexity channelizer.

To decrease high computational complexity of narrow transition bandwidth filter bank, In [15] provided the less complexity channelizer depending about the FRM. To build a prototype filter of present low-complexity channelize based on FRM, the half-band filter was utilized. The results of simulation and complexity analysis predict low-complexity channelizer proposed was accurate and decreased calculational and hardware complexities considerably. Two-tier and interleaving schemes utilizing NMDFB explained in paper [16] were best methods in channelizer design. Although it have some drawbacks includes reduced reconfigurability and reduced flexibility in the production of the large number of stringent bandwidth and very sharp transition width responses. Benefit is that it requires limited resources and, while the delay is a major issue, has less difficulty.

3. Methodology

3.1. Frequency Response Masking Techniques

For designing digital filters with sharp transition bands, FRM method [17] was acceptable. The combination of wide transition band filters, typically known model filter and masking filter, achieves a sharp transition bandwidth. The model filter was upsampled for develop periodic model filter that, as a result of upsampling, compress frequency response of filter for obtain an optimal frequency band with a sharp transition band. Also, due to the upsampling, there were extra frequency components in spectrum. These spectral filters are eliminated by cascading the model filter with masking filters.

The cascading of periodic filters with non-periodic filters for achieve sharp transition band the FRM structure method in Fig1, allowing arbitrary-bandpass FIR filters with low hardware complexity to be implemented, as most filter coefficients were zero. The hardware complexity of FIR filters could decreased by utilizing Frequency Response Masking approach for designing FIR filter with some multipliers [18]. sparse nature of Frequency Response Masking filter coefficients makes the filter low hardware complex for high-resolution uses. Provided the prototype symmetrical impulse response linear phase low-pass filter $S_a(z)$ a known as Model filter or prototype filter for order L_a, the complementary filter $S_c(z)$ could represented as,

$$S_c(z) = z^{-(L_a-1)/2 - S_a(z)} \quad (1)$$

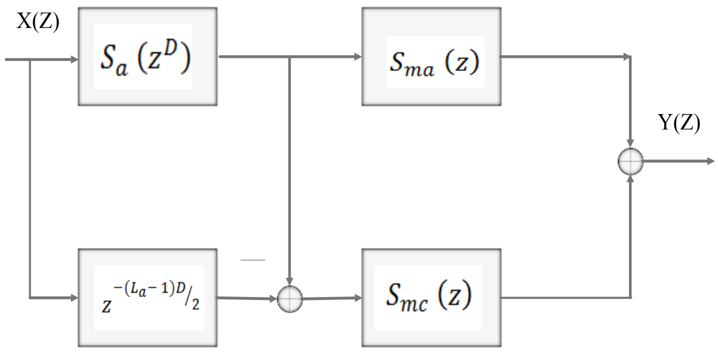

Fig 1. FRM Structure

By replacing the D delays outcoming in interpolated linear-phase FIR filters [19] $S_a(z^D)$ and$S_c(z^D)$, delay of the model filter such as $S_a(z)$ and $S_c(z)$ is removed successfully. The transition width of these IFIR filter is $\frac{1}{D}$ times that of $S_a(z)$.In Frequency Response Masking techniques, both masking filters $S_{ma}(z)$ $S_{mc}(z)$ are cascade to $S_a(z^D)$ and $S_c(z^D)$, respectively, as given in Figure.2. Transfer function for filter was provided by [27],

$$S(z) = S_a(z^D)S_{ma}(z) + S_c(z^D)S_{mc}(z) \quad (2)$$

Equation 3 can be expressed using (1) and (2) as follow,

$$S(z) = S_a(z^D)S_{ma}(z) + z^{-\left(\frac{L_a-1}{2}\right)D} - S_a(z^D)S_{mc}(z) \quad (3)$$

In FRM, the prototype model filter $S(z)$ was interpolated by various values that is 2, 4, 8, 16 and 32 or interpolated factor and by cascading the interpolated sub-filters include $S(z)$ or $S_c(z)$ might produce needed bandpass filters. Therefore by suitable choosing of passband and stopband edges of modal and masking filters, any sharp transition-band FIR filter could implemented with less complexity. Modified Frequency Response Masking using IFIR was presented to be following in Fig.4,

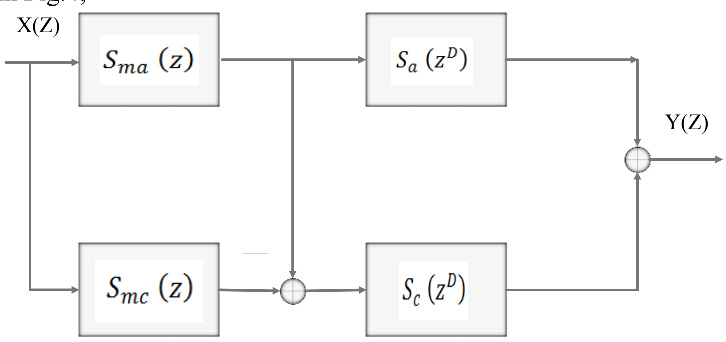

Fig 2. Modified FRM

When using the wideband system in signal processing, increased sampling frequency and data rates that occur in many operations per second are needed. The multi-rate decimation and interpolation operations that have been implemented decompose any system function H(z) into its polyphase representation[20].

3.2. Proposed Non-Maximally Coefficient Symmetry Multi Rate Filter Bank

In this section, the Non-Maximally Coefficient Symmetry Multirate Filter Bank is proposed to reduce the delay and hardware complexity for a wideband channelizer. The new design is based on the Reconfigurable FRM framework in which interpolated linear phase FIR filters were utilized to understand the non-maximally polyphase decimated filter. Also, different masking responses were realized utilizing NMDFB in this structure. advantage of utilizing architecture is the single analysis filter bank could utilized to recognize responses of two masking filters. The selection of the channel is applied to the inputs of the appropriate synthesis bank. Thus, utilizing the method of the single analysis filter bank and both synthesis filter banks, entire masking procedure can be understood. Ininstances, where complexity of specification was a significant role, the architecture can be chosen based on the modal filter order and prototype filter analysis was built, as shown in Fig.3. Also, it is possible to integrate hardware-level optimization into the updated FRM approaches employing coefficient symmetry in NMDFB polyphase filters to improve the efficiency of hardware and flexibility of presented schemes.

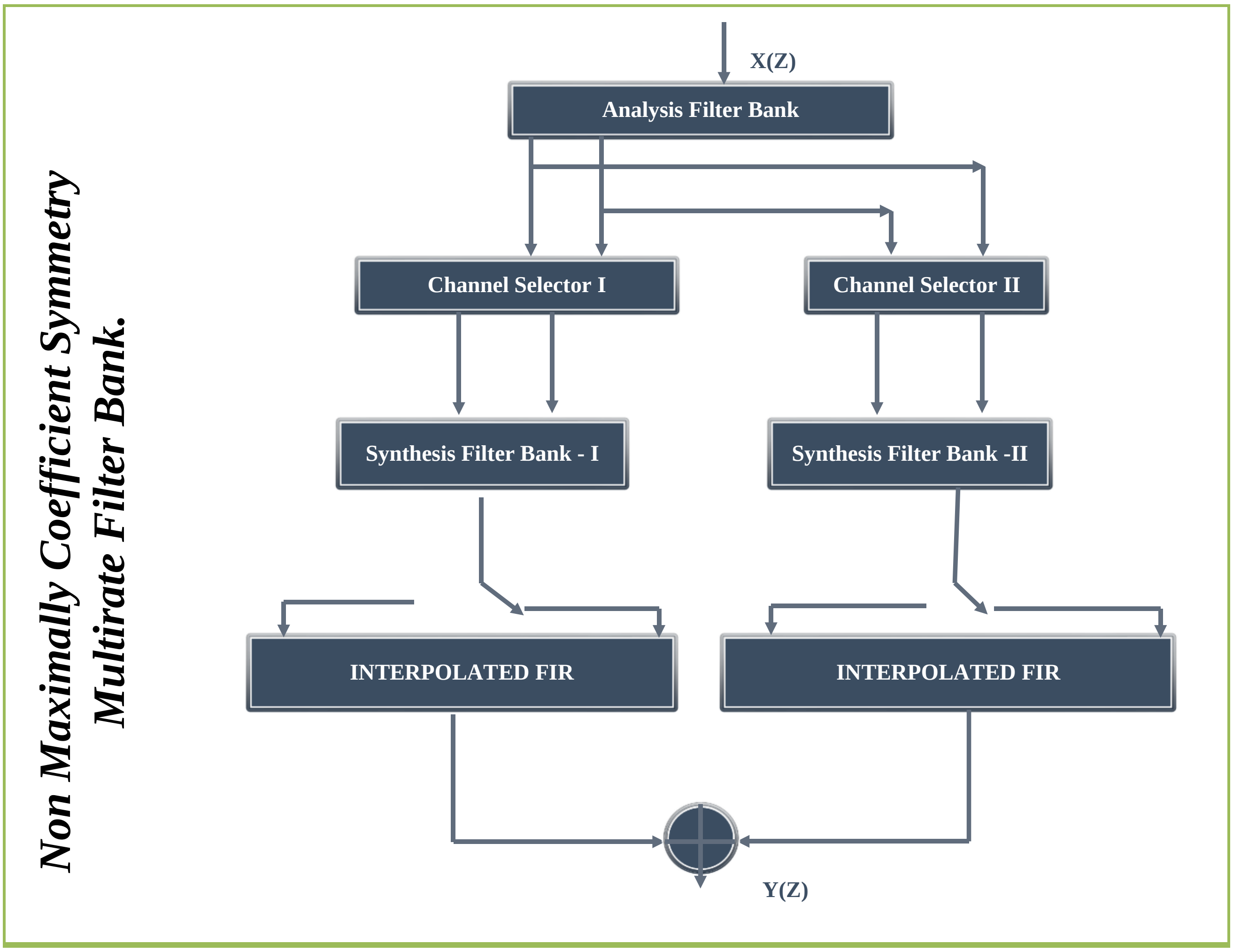

Fig 3. Proposed Non-Maximally Polyphase Decimated Filter

1) Non Maximally Decimated Polyphase Filter Bank

Polyphase was the way for doing sampling-rate conversion which leads to high efficient implementations. Using this implementing of polyphase decompose, the polyphase filter was designed [21]. A polyphase bank comprises of the analysis stage and the synthesis stage of prototype filters offers good power efficiency. Each stage consists of a set of filters in parallel. Depend on decimation factor utilized polyphase filter banks could categorized as maximally and non-maximally decimated. In maximally decimated polyphase filter banks, there might be aliasing among adjacent bands of every polyphase path. This restricts their utilize on high-spectral-resolution uses. NMDFB [22] faces the aliasing issue by rising the channel spacing. Therefore the polyphase NMDFB system was utilized in the work.

The changed structure where, decimated factor < M -channel, of the single filter, could designed for satisfying perfect construction property and could process any arbitrarily situated frequencies without folding noise. Usually, in NMDFBs, D was taken as M/2. Thus, the outcome sampling frequency was twiced that is it becomes $2 * \frac{sampling\ rate}{M}$ instead of $\frac{sampling\ rate}{M}$ as maximally decimated filter bank. It is achieved by Polyphase Analysis and Synthesis Filter Bank for Non-maximally decimated filter bank as follow,

M-path polyphase decomposition of prototype filter was provided as [28]

$$H(z) = \sum_{k=0}^{M-1} z^{-ke^{\frac{j2\pi mk}{M}}} C_k\left(z^{\frac{M}{D}}\right), 0 \le m \le M-1 \quad (4)$$

where, $k = 0, 1, 2, \ldots, M-1$, D was a decimation factor, M-parallel paths, m was a channel number and $C_k\left(z^{\frac{M}{D}}\right)$were kth polyphase components achieved by polyphase decomposition of $H(z)$ where, a M-path delayed down-sampled commutator accepts M/2 input data sequences at the sampling frequency of fs and produce result samples at the frequency of $2 * \frac{sampling\ rate}{M}$. Hence, the polyphase representation of analysis and synthesis filter will be modified as,

$$A_{m}^{p}(z) = \sum_{k=0}^{M-1} z^{-k} \quad e^{\frac{j2\pi mk}{M}} \; C_k\left(z^{\frac{M}{D}}\right), 0 \leq m \leq M-1 \quad (5)$$

(5)

$$S_{m}^{p}(z) = \sum_{k=0}^{M-1} z^{-k} \quad e^{\frac{j2\pi mk}{M}} \; C_k\left(z^{\frac{M}{D}}\right), 0 \leq m \leq M-1 \quad (6)$$

$A_{m}^{p}(z) and\ S_{m}^{p}(z)$ can also expressed as given, [26] based on Aliasing cancellation condition, Distortionless condition

$$A_{m}^{p}(z) = A(zW_M) \quad (7)$$

$$S_{m}^{p}(z) = S(zW_M) \quad (8)$$

Condition for eliminating the folding noise or aliasing

$$A^{p}\,(zW_D^d)S^{p}(z) = 0;\ \forall d = 1,2, \ldots D-1 \quad (9)$$

These equations impose the condition in responses of $A_{m}^{p}(z)$ and $S_{m}^{p}(z)$ such that $S_{m}^{p}(z)$ and shifted versions of $A_{m}^{p}(z)$may has reduced overlap for ensure reduced aliasing. By properly setting passband and stopband frequencies of prototype filters as well as choosing filters with a increased stopband performance, aliasing energy could be decreased to considerably less value. Therefore, NMDFB was recommended over MDFB for wideband Software Defined Radio channelizer designs.

2) Coefficient Symmetry In Non-Maximally Coefficient Symmetry Multi Rate Filter Bank

Reducing the complexity of filter banks have became a concern research topic in final decades. For that, symmetric has been successfully used in the design of digital filter banks in resulting required optimization and better response characteristic are obtain and continuously minimizing the complexity of filter banks [23]. In this manner, we have presented the coefficient symmetric approach for modified FRM techniques using non maximally polyphase filters to decrease the use for multipliers in FB. To utilize the coefficient symmetry of modified FRM techniques using non maximally polyphase filters, we has presented deduced transfer function expressions. It was shown that a presented structures could decrease multiplication complexity by factor of 2 over the filter coefficient or sub-filters. overall transfer function of the proposed filter for every arbitrary positive integer values for N and M using coefficient symmetry is derived under the two cases as follow,

a) While sub filters order of filter structure was even $(N\backslash M)$,
b) While sub filters order of filter structure was odd $(N\backslash M)$,

3) Deciminator

When sub filters order of filter structure was even,

In this condition, the transfer function of modified FRM techniques using non maximally polyphase filters using the equation ($A\ (z)$) is Could expressed as below from [29],

$$\mathrm{A(z)or(z)} = \sum_{k=0}^{R-1} z^{-k} \left(C_{k,1}^{R}\,(z^M) + z^{-M\left[\frac{N}{M}\right]/2}\, C_{k',1'}^{R}(z^M))\right) + \sum_{k=R}^{\left[\frac{M+R}{2}-1\right]} z^{-k}\, C_{k,1}^{S1}\,(z^M) + z^{-M\left[\frac{N}{M}\right]/2} C_{k'',1'}^{S1}(z^M)\,) + \sum_{k=\frac{M+R}{2}}^{M-1} z^{-k} \quad C_{k,1}^{S1}\,(z^M) z^{-M\left[\frac{N}{M}\right]/1} C_{k'',1'}^{S2}(z^M)\,) \quad (10)$$

where, M represents number of parallel connected sub filters, N denotes order of filter, $N\backslash M$ indicates the sub filters order of the polyphase structure, $R = N - M(\left\lceil\frac{N}{M}\right\rceil)$+ M and k,$k'$, k'' are complementary sub filters.

When sub filters order of the filter structure is odd,

In this condition, the transfer function of modified FRM techniques using non maximally polyphase filters using the equation (A (z)) is could expressed as below,

$$\mathrm{A(z)}= \sum_{k=0}^{\left\lceil\frac{R}{2}-1\right\rceil} z^{-k} \left(C_{k,1}^{R1}\,(z^M) + z^{-M\left[\frac{N}{M}+1\right]/2}\, C_{k',1'}^{R1}(z^M))\right) + \sum_{k=\left\lceil\frac{R}{2}\right\rceil}^{[R-1]} z^{-k}\, C_{k,1}^{S2}\,(z^M) + z^{-M\left[\frac{N}{M}\right]/2} C_{k'',1'}^{S2}(z^M)\,)$$

$$+ \sum_{k=R}^{M-1} z^{-k} \quad C_{k,1}^{S}\,(z^M) + z^{-M\left[\frac{N}{M}-1\right]/2} C_{k'',1'}^{S}(z^M) \quad (11)$$

a) Numerical Analysis Using Positive Integer Values of ***N*** *And* ***M***

Considered, R= M, M = 4 and N=16 into using this following equation even (10), the transfer function of proposed filter structure could be represented as,

$$\mathrm{A\ (z)} = \sum_{k=0}^{3} z^{-k} \; \left(\sum_{l=0}^{1} h_{4l+kz^{-4l}}\right) + z^{-8} \; \sum_{u=0}^{1} h_{4u+k'z^{-4(1-u)}}$$

(12)

Using this equation, higher index coefficients in subfilters of the proposed filter is rejected and particular symmetric low index coefficients. Moreover, the multiplier unit is N\2 instead of conventional polyphse filter for multirate system. Considered J=M=4 in equation (11), higher index coefficients in subfilters of the proposed filter is rejected and particular symmetric low index coefficients. Moreover, the multiplier unit is N\2. Furthermore, it can easily be recognized that the structure applicable for designing the proposed designing of multi-rate systems. Accordingly, we consider poly phase structure along with downsampler (J) of M=J=4 was inserted at end of filter result after selecting suitable filter coefficients. (that is for demonstration, c0; c1; c2; c3; c4; c5; c6; c7; c8; c9; c10; c11; c12; c13; c14; and c15). After using noble identities, downsampler was inserted at filter result could be equivalently replaced by 4 down samplers at point B1, B2, B3, and B4 and Hereby, that structure will work as the decimator as shown in Fig. 4.

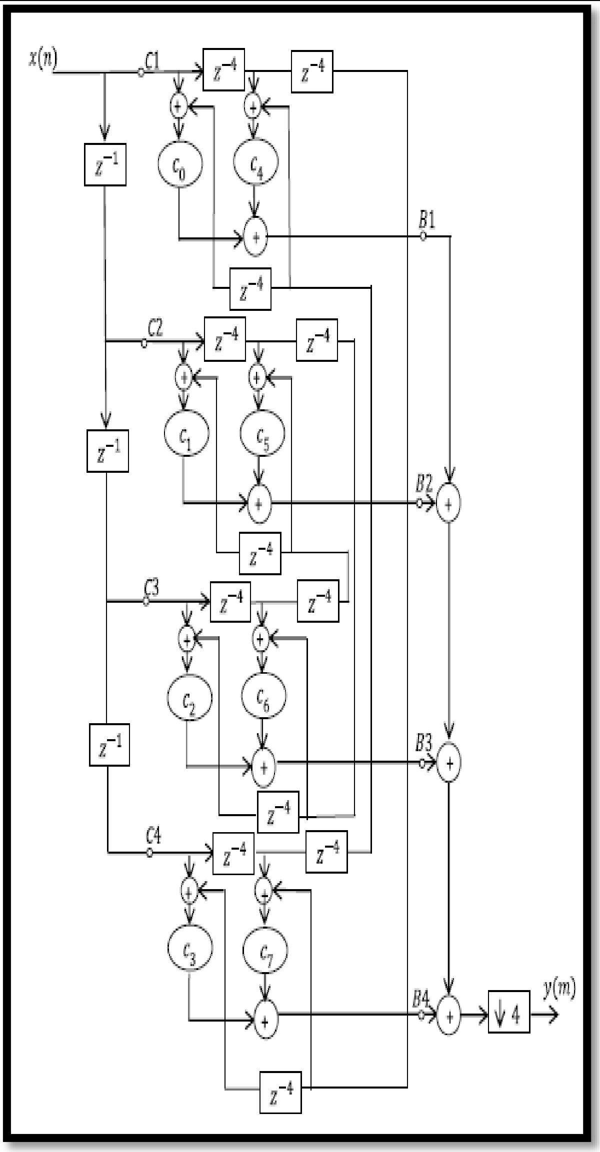

Figure 4. Conventional Polyphase Structure for Deciminator

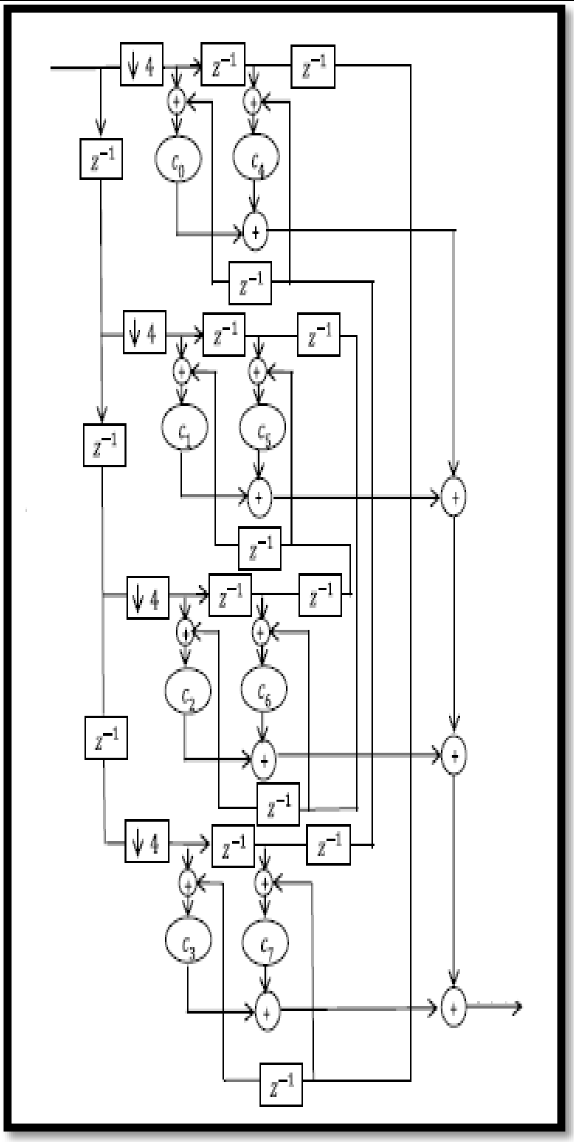

Figure 5. Modified Polyphase Structure for Deciminator

Although it was not able for perform filtering operation at reduced sample rate. And also, four down samplers could equivalently shifted to point C1, C2, C3 and C4 replacing each delay elements fromz^{-4} to z^{-1}as shown in Fig.5. Although desired decimator could realized at reduced sample rate. In modified FRM using the non maximally polyphase filter, two synthesis filter bank is used for wideband channelizer. In which, the efficient transposed interpolator design is achieved using coefficient symmetry.

4) Transformed Interpolator

While sub filters order of the filter structure is even,

$$S(z) = \sum_{k=0}^{R-1} z^{-k} \left(C^{R}_{k,1}(z^M) + C^{R}_{k',1}(z^M)\right) + \sum_{k=R}^{\left\lceil \frac{M+R}{2}-1\right\rceil} z^{-k}\, C^{S1}_{k,1}(z^M) + C^{S1}_{k'',1}(z^M)) + \sum_{k=\lceil M+R/2\rceil}^{M-1} z^{-k}\quad C^{S}_{k,1}(z^M) + C^{S2}_{k'',1'}(z^M)) \qquad (13)$$

When sub filters order of the filter structure is odd,

$$S(z) = \sum_{k=0}^{\left\lceil \frac{R}{2}\right\rceil-1} z^{-k} \left(C^{R1}_{k,1}(z^M) + C^{R1}_{k',1}(z^M))\right) + \sum_{k=\left\lceil \frac{R}{2}\right\rceil}^{[R-1]} z^{-k}\, C^{S2}_{k,1}(z^M) + C^{S2}_{k'',1}(z^M)) + \sum_{k=R}^{M-1} z^{-k}\quad C^{S}_{k,1}(z^M) + C^{S}_{k'',1}(z^M)) \qquad (14)$$

Considered, R= J, J = 4 and N=16 with every coefficient were positive into using this following equation even (13), transfer function for proposed transforsm filter structure could expressed as, S(z)=

$$\sum_{k=0}^{3} z^{-k} \left(\sum_{l=0}^{1} h_{4l+kz^{-4l}}\right) + \sum_{u=0}^{1} h_{(4u+k'z^{-4(1-u)})z^{-12+8u}} \quad (15)$$

Using this equation (15) on the conventional transposed polyphase FIR structure and proposed transposed architure to evaluate the multipler count. Thus, the N\2 multiplier is required instead of N. Correspondingly, we consider conventional transposed polyphase structure along with upsampler (L) of M=L=4 was inserted at end of filter result after selecting suitable filter coefficients. (that is for illustration, c0; c1; c2; c3; c4; c5; c6; c7; c8; c9; c10; c11; c12; c13; c14; and c15). After using noble identities, downsampler that was provided at filter result could equivalently replaced by 4 upsamplers at point B1, B2, B3, and B4 and Hereby, that structure will work as the interpolator given in Figure. 6. Although it performs filtering operation at a increased sample rate. That is $4f_{in}$. So that, the four upsamplers could equivalently shifted to point C1, C2, C3 and C4 by replacing every delay elements from z^{-4} to z^{-1} as shown on Figure.7. Although, it carries out the filtering process at a higher sample rate. That is, f_{in}.And also it was worth founded that filter structures (that is for even (10, 13) and odd (11, 14)) were used to design multi-rate systems.

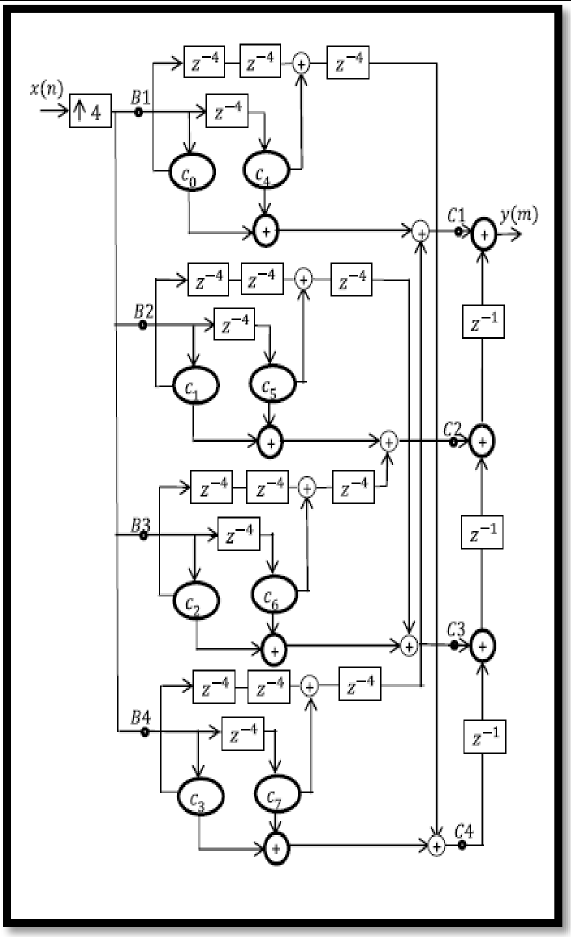

Figure 6. Conventional Transformed Polyphase Structure for Interpolator

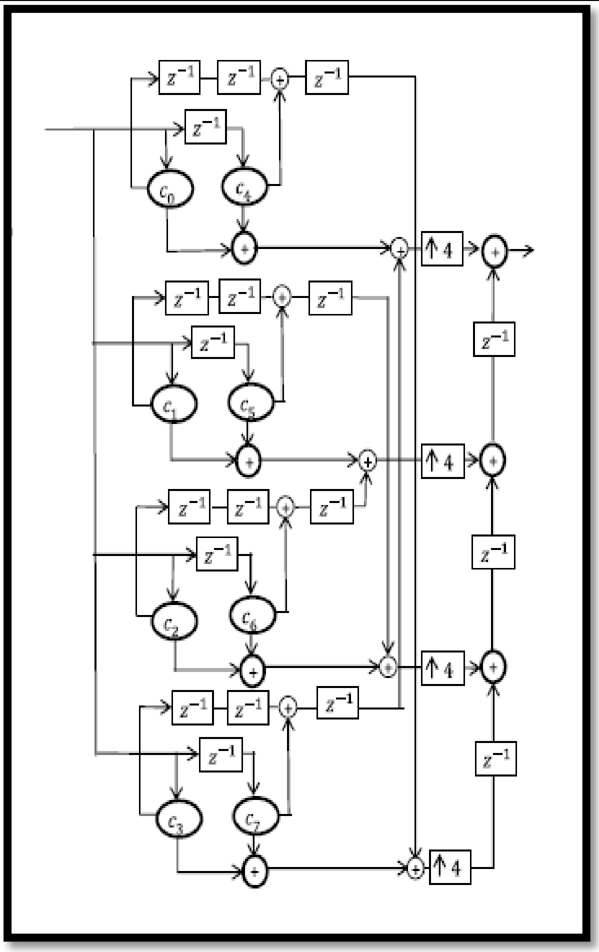

Figure 7. Modified Transformed Polyphase Structure for Interpolator

4. Result

The performance of the reconfigurability, power efficiency and low complexity for reconfigurable channel filter/filter banks of cell phone receivers is discussed in this section. For that, the wideband channel of communication standards includes QPSK, FSK, and PSK is used to analyze the proposed filters. Moreover, the intends to prove advantage of presented filter while compared to new techniques, communication standards. All simulations are done in MATLAB.

To prove the feature of phase and magnitude to verify the proposed Non-Maximally Coefficient Symmetry Multirate Filter Bank, we assumed the example to J = 4 and N =16. For a valid comparison, we plotted phase and magnitude characteristics for the proposed filter bank, given on Fig3. This can be noticed from Figs. 4 and 5 that we can obtain the particular magnitude by inserting the magnitudes of k D 0; 1; 2; 3 sub-filters with their corresponding phases. Besides, each sub-group filter's delay is static, leading to the linear phase of the proposed Multirate Filter Bank Non-Maximally Coefficient Symmetry. In successful decimator and interpolator structures, these linear-phase characteristics may provide the ability to review the signal on sub-filters beyond phase loss. The resulting gain response of proposed filter was given as Figure. 8.

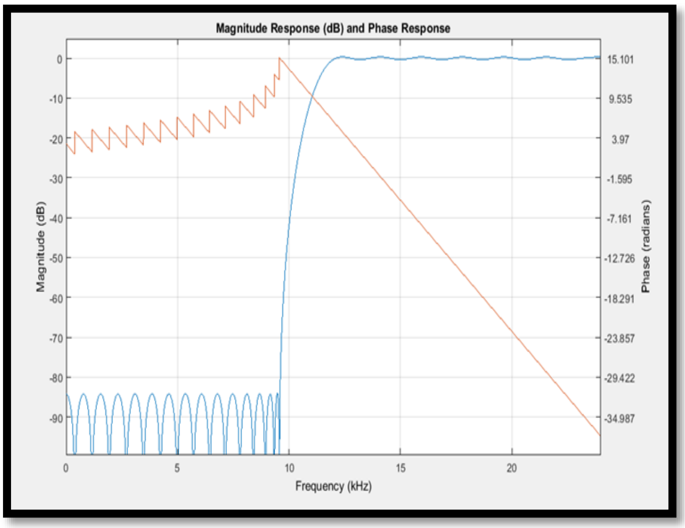

Fig 8. Magnitude and Phase Response

We have also provided the features of the proposed filter phase and magnitude, as given in Figures. 9 and 10, respectively.

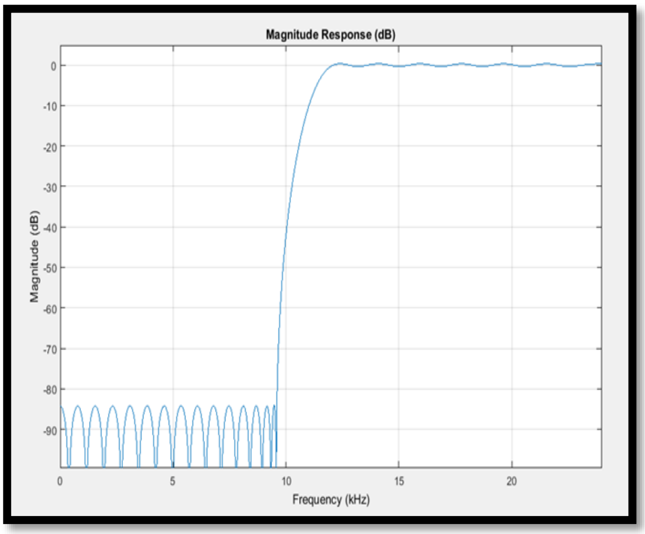

Fig 9. Magnitude Response

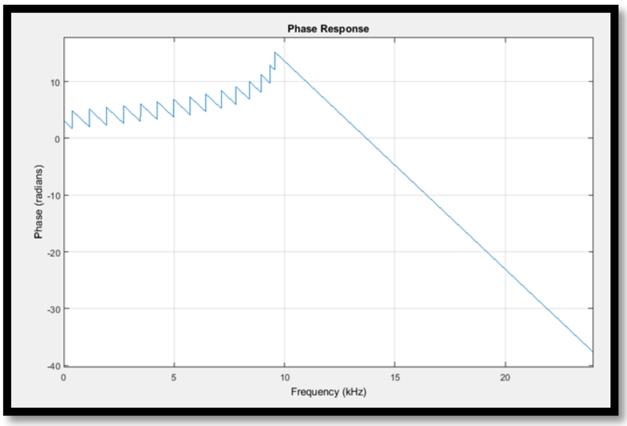

Fig 10. Phase Response

As they flow through a filter, all the frequency components of a signal are postponed. The time delay of the signal through the system under test as a function of frequency is also called a Group delay in a filter. The group delay for every subfilter was constant, that contributes to linear process of the filter being presented and is expressed in Figure.11

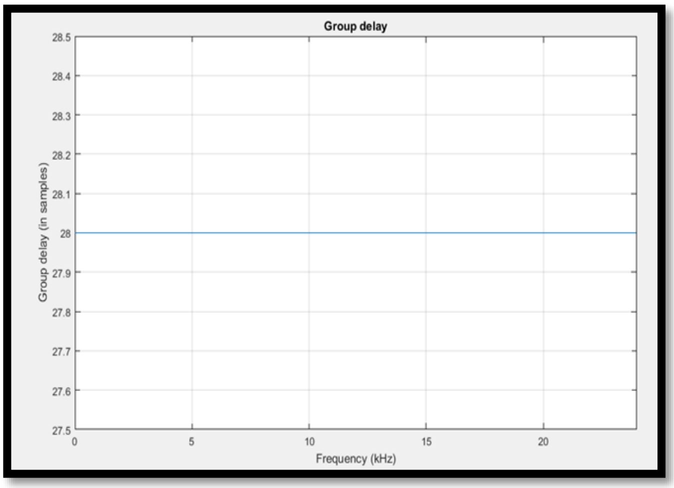

Fig 11. Group Delay

Many multipliers needed for presented filter was tabulated and compared with the techniques mentioned in [24, 25] in Table 1.

TABLE.I HARDWARE COMPLEXITY COMPARISION

S. No	Method	Number of Multipliers
1	Non –Uniform filter	918
2	VBW masking method	616
3	Proposed Filter	57

The number of multipliers is decreased by utilizing the coefficient symmetry of polyphase components. Whereas the multiplier requirement is almost minimized by manipulating the coefficient symmetry, which could easily founded from Table 1 that traditional polyphase framework empowers multiplier units to be the similar as filter order. Although, as coefficient symmetry is manipulated, the multiplier criteria decreases and our proposed Table 1 solution decreases rm. The power consumption is effectively controlled by promoting the proposed filter in term of complexity and delay.

Besides, this proposed filter explores whether the wideband channel is assisted. With regards to, communication standards includes QPSK, FSK, and PSK are provided the input of proposed filter. Then, the normalized magnitude-based frequency response is evaluated. The communication standards are realized using a proposed filter in Figs. 12.

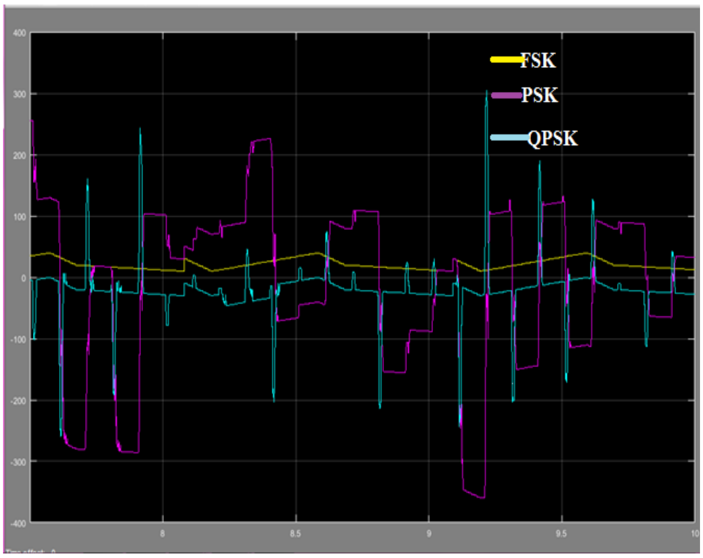

Fig 12. Communication Standard realized using proposed filter

5. Conclusion

The Non-Maximally Coefficient Symmetry Multirate Filter Bank, recommended to high-resolution wideband channel, is proposed in this paper. In this proposal, a reconfigurable NMDFB architecture modifies the basic FRM structure. Moreover, coefficient symmetry in the proposed filter is exploited in the proposed schemes. For that, we has derived transfer function expressions under coefficient symmetry for polyphase FIR filters via the interpolator design transposed by the decimator design. In addition, we have provided the proposed filter bank's phase and magnitude properties. To improve the hardware efficiency and functionality for presented schemes, hardware-level optimization could also implemented into changed Frequency Response Masking methods.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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